To decide which of these explanations is correct, a vessel was filled with spongy iron and distilled water, the air being expelled from the former as far as practicable. After three months' standing, I analyzed the gas, collected as before by inserting a rod into the spongy iron. I found that it neither contained hydrogen nor carbon, therefore most probably consisted only of atmospheric nitrogen. This appears to indicate that the carbon, which was obtained in the previous experiment, is actually the result of the decomposition of organic matter.

The connexion between disease and impure water, more especially if it be contaminated by putrescent organic matter, has been strongly urged by various authorities, such as Drs. Buchanan, Frankland, Sanderson, Simon, Tyndall, and others. This has led me to attach such importance to the demonstration that "living ferments" are absent from polluted water after filtration through spongy iron. Analytical figures, in their turn, have proved that even Thames water can by filtration through this material be made, chemically speaking, purer than some of the best deep well waters. As the latter are mostly more or less supplied by polluted surface water, which is purified by filtration in passing downwards, there is no reason why they should be preferred to artificially filtered water, provided the physiological character of both proves to be alike. This inquiry is at the present moment being officially instituted in several countries. Trustworthy evidence in the form of actual experience may thus ere long be expected to settle the final question, whether and how far the artificial purification of impure water by spongy iron can be considered a safeguard against the propagation of disease.

II. "On the Modifications of the Simple and Compound Eyes of Insects." By B. Thompson Lowne, F.R.C.S., Lecturer on Physiology at the Middlesex Hospital Medical School, Arris and Gale Lecturer on Anatomy and Physiology in the Royal College of Surgeons. Communicated by Professor Flower, F.R.S. Received February 27, 1878.

(Abstract.)

The simple eyes of insects have been so accurately described by previous observers, that little need be said on their structure. I have described the simple eye of *Eristalis*, chiefly for comparison with the compound and aggregate eyes. The close relation of the recipient rods to the inner surface of the cornea in this insect is most noteworthy, since, combined with the great convexity of the cornea and the highly refractive nature of the rods themselves, this renders the formation of an optical picture impossible. These facts with the small

number of recipient rods shew that it is most probable that the function of the ocelli is rather the perception of the intensity and the direction of light than of the actual disposition and colours of surrounding objects.

The compound eyes of insects are of two kinds; an intermediate condition between the simple and compound eye, closely resembling the aggregate eyes of other anthropods, which I have at present only found in the Nematocerous Diptera, and in the bees, wasps, and ants, the only examples of the Hymenoptera in which I have examined the eyes; and the true compound eye, found in the majority of insects.

I strongly suspect that further observations will show that the aggregate form of eye is also characteristic of the Hemiptera and of a large number of the Coleoptera; I hold this view, from a casual observation of the eyes of several species of Hemiptera, as well as from the imperfect description of the eyes of these insects in Dr. Grenacher's recent paper.

I have examined and described the eyes of *Tipula*, *Formica*, and *Vespa*, which are examples of very highly modified aggregate eyes. In these insects each facet of the cornea has sixteen recipient rod cells behind it. In *Tipula* these are so deeply pigmented, that in the adult insect it is impossible to get a transparent section; although I have adopted the method described by Dr. Schaefer in the preparation of fine sections of the mammalian ovum,* of imbedding the specimen in cacao butter, and have cut sections of certainly not more than $\frac{1}{10000}$ of an inch in thickness. These have been examined with a sixteenth immersion of Nachet's.

The nearest approach to these deeply pigmented cells is seen in the red cones in the eye of the pigeon, described by Max Schultze,† or perhaps in the deeply coloured rods of the eel (Kühne).‡ But, unlike the latter, the pigmented parts of the eyes of insects, as far as my observations go, are unaffected by light, and the same observation has been made by Kühne with regard to the colour in the so-called rods in the eye of the lobster.§

Behind the corneal facet, and immediately in relation with it, each rod-cell has a minute highly refractive spherule; this is of an intense purple colour in the eye of *Vespa* and *Tipula*, but it is colourless in the eye of *Formica rufa*. It is exceedingly like the globule found between the inner and outer segments of the cones in many birds.

Behind the rod-cells a very remarkable structure is found which has hitherto escaped detection, except by Dr. Grenacher,|| who describes it under the name retinula. As this term is, however, applied by him to

* "Proc. Roy. Soc." † "Archiv," Bd. iii.

‡ Kühne "Untersuch. aus dem Physiolog. Inst. der Univ. Heidelberg," Bd. i, Hft. i. § *Ibid*, hft. ii.

|| "Zehender's Monatsblatt. Beigeheft," 1877.

structures in other insects which are perhaps very different, and as it tends at least to give an erroneous idea of its nature, I have preferred to call it the *facellus.*

The facellus consists of a cylindrical or fusiform bundle of seven or more—twelve at least in the ant—fusiform cells, each of which has a fine axial thread of highly refractive material. This thread is prolonged from the outer extremity of the facellar cell into the rod-cell layer above described. These threads pass also into the deeper structure beneath the facellus, which I have named the *stemon.*

The stemon is the large rod-like organ which connects the facellus with the ganglionic retina. The stemon of each central facet remains distinct through its whole course, but those of the peripheral facets unite in bundles of four or more near their inner extremities. In *Tipula* each stemon, whether simple or compound, divides at its inner extremity into several irregular fine branches which pass into stellate highly pigmented cells (ganglion cells ?). The inner processes of these cells connect them with the round cells of the ganglionic retina. In the ant and in the wasp, the stemonata do not divide at their inner extremities. In the latter I have not been at present successful in tracing the connexion of the stemon and the nervous structures beneath; but, in the former, each stemon is connected with the ganglionic retina by what appears at first sight to be a thick nerve fibre. From observations on the eyes of Lepidoptera, where similar thick nerve fibres exist, I conclude that, in both cases, these are compound fibres consisting of a large number of primitive fibrillæ. The ganglionic retina in the ant consists exclusively of small round cells; I have been unable to detect either stellate corpuscles or fusiform cells, which are so constant in this organ in insects.

In the third form of eye, the true compound eye, the facets are each provided with a single complex rod-like structure, which I have called the rhabdion, in accordance with the nomenclature proposed by Dr. Grenacher.

The nature of this structure is best seen in the eyes of the crepuscularian Lepidoptera. In the eyes of the Sphingidæ a single rhabdion rests on a distinct facellus, quite comparable, indeed almost identical, with that of the semi-compound eye. The rhabdion is separated from the corneal facet by a cone, described under the term crystal-cone (*krystal-kegel*). The facelli are continuous with thick nerve fibres, which are undoubted compound. These are gathered together into nerve trunks, the fibres from thirty or forty facelli being united into a single trunk, which branches at its inner extremity, and is connected with numerous ganglion cells.

The cone consists of eight cells—Four are superficial, that is, they are in contact with the corneal facet; these remain soft; they have been spoken of by previous writers as " Sempers' cells," and have been

confounded with sub-corneal nuclei of the eye in the Diptera and some other insects, but they are, I believe, very different structures, morphologically speaking. The other four form the hard cone, or, as I shall call it, the scleral cone. These remain distinct throughout the life of the insect, as the cone always splits most readily into four equal segments corresponding to the four primitive cells.

An examination of the eye in moths has shown that the segments of the scleral cone are prolonged as threads into the rhabdion. The threads are apparently viscous immediately after death, as they are liable to contract and form globular or pear-shaped drops, as the inner segments of the rods and cones of some vertebrates do, according to the observations of Max Schultze.*

The chamber in which the cone lies is usually lined with pigment cells. These are very remarkable in structure, reminding me of the retinal pigment cells of vertebrates; they are generally arranged round the apex of the cone, and give off numerous thread-like processes which surround the cone.

Although the compound eye in insects exhibits very considerable modifications in different families, the researches of Claperede† show that these are all developed from a condition closely resembling the type I have just described. The primitive zone consists of eight cells: four of which Claperede speaks of as the cells of "Semper," and four of which he terms cells of the cone. There is every reason to believe that the scleral structures are formed in the interior of the latter, which, in moths, become entirely converted into scleral tissue; the same occurs, according to Leydig,‡ in some Coleoptera, as *Cantharis melanura* and *Elater noctiluca:* I have observed the same thing in the eye of *Dytiscus*, and, as is well known, this condition appertains in *Hyperia*, amongst the Crustacea.

I think there is little doubt, from the observations of Leydig and Dr. Grenacher, that the eyes of most, if not of all, the pentamerous Coleoptera retain the primitive structure of the cone throughout life, and those of many Crustacea present cones which are either partially or entirely converted into scleral tissue.§

I propose to term these two forms of eye, proto- and sclero-conic.

Starting from the proto-conic eye: There are two extreme forms of deviation; in the one, the cone disappears, and its place is occupied by a slightly coagulable fluid. This is the case in the eyes of the heterocerous Diptera. In these insects four portions of protoplasm remain attached to the outer extremity of the rhabdion; further observations are needed in the development of these structures, and as to the origin of the fluid; but analogy, with the conditions in some of the

* "Archiv.," Bd. iii. † "Kol. Zeitsch.," Bd. viii.

‡ "Müller's Archiv.," 1855.

§ Newton, "Eye of the Lobster," "Quarterly Journ. Mic. Sc.," 1874.

Lepidoptera, renders it highly probable that the four bodies are the nuclei of the primitive cells of the cone, and that the remainder of these cells undergoes liquefaction. The four bodies in question are elipsoids, with their long axes at right angles to the plane of the cornea; they exhibit fine longitudinal striations. I have called the compound organ formed of these four bodies, the *tetrasome.*

In the other type of eye, the chamber contains a fluid formed by the liquefaction of a portion of the cells of the primitive cone; but a remarkable body is developed in the interior of these cells of a very complex nature. It consists of a tetrasome, formed of four minute highly refractive spheres, supported on a *tetraphore*. I think it probable that the tetrasome is formed from the nuclei of the four superficial cells of the cone, whilst the tetraphore appears to be a highly modified scleral cone formed in the interior of the deeper cells; but the whole question of the development of these parts is very difficult, and requires further investigation.

I have used the terms hydroconic and tetraphoric to designate these two forms of eye. The first is characteristic of the heterocerous Diptera and Libellulidæ; the second occurs in *Acridium*, and in the diurnal Lepidoptera, *Vanessa*, *Pieris*, *Colias*, and *Goneptrix.*

The rhabdion is either prismatic or cylindrical. In the eye of the pupa it is seen to be formed of four cells; but in the imago these are so closely united that they can no longer be recognized as separate structures. It contains axial longitudinal striæ, which appear to be the internal prolongations of the highly refractive cone or tetrasome.

In the Lepidoptera the rhabdion rests on a facellus, formed of seven fusiform cells, or, in some cases, of as many cylindrical rods, but in the Diptera, Dragon flies, and some saltatorial Orthoptera it is in immediate relation with the outer stellate ganglion cells of the ganglionic retina. In the Diptera the rhabdia of the two peripheral rows of facets are, however, united into bundles of four or more at their inner extremities; at least, this is the case in the Syrphidæ; and these bundles are surrounded by fusiform pigmented cells in such a manner that they somewhat resemble a facellus.

The Diptera have, however, a very remarkable layer in the ganglionic retina itself, which apparently represents the facellus in function at least; I have termed it the facelloid layer.

The accompanying diagram represents the axial structures connected with a single rod-cell, in the semi-compound eye, and with one segment of the cone or tetrasome in the true compound eye.

The rhabdia in the compound eye are surrounded in most insects by a close network of tracheal tubes, but in the Diptera these are replaced by sac-like trachea which fill the interspaces between the prismatic rhabdia; this arrangement has been described by Leydig.

The nervous structures of the retina and optic ganglia of the eyes of

insects are exceedingly difficult to make out; but I think I have succeeded in working out the retinal structures of *Eristalis* and *Agrion* in considerable detail. In the other insects in which I have examined the eye, the knowledge which I have been able to obtain of this portion of the nervous system, must be considered at present as fragmentary. In *Eristalis* there are from without inwards:—1. A double layer of large stellate ganglion cells; 2. A layer of small round nucleated cells; 3. The facelloid layer already referred to; and 4. A layer of stellate ganglion cells.

These parts are connected with a deep ganglion, which consists of several layers of fusiform cells by a decussating optic nerve, the fibres of which cross each other from above downwards, and from without inwards. The deep ganglion is connected by a distinct peduncle with the supra-œsophageal ganglion. All the structures of the ganglionic retina are supported by a fine neuroglia, which extends from a thick outer to a fine inner limiting membrane.

In *Agrion* the ganglionic retina differs from that of *Eristalis* in the absence of a facelloid layer, which is replaced by a triple layer of prismatic cells: the investigation of the nerve structures of this insect is rendered very difficult by the presence of a large quantity of dark pigment in the stellate connective cells of the neuroglia.

In *Vanessa* the facelloid layer of the retina is also absent, but in its place there are numerous layers of fusiform cells. In noctuid moths, or at least in some species, the nervous structures are obscured by the large quantity of deep black pigment which they contain. In the semi-compound, or, as I have termed it, the *microrhabdic* eye of *Tipula*, the nervous retina consists of, (1,) a layer of stellate ganglion cells; (2,) of several layers of round cells; and (3,) of several layers of fusiform cells. The greatest simplicity exists in the eye of *Formica*, in which all the structures of the nervous retina are absent except numerous layers of small round cells. I have not at present been able to make out any decussation of the nerve fibres connecting the deeper parts with the ganglionic retina in the insects with microrhabdic eyes, but the investigation is very difficult, owing to the great change of the plane in which the nerve tracts lie. I do not think, however, that any decussation exists, or I think I should have found indications of it.

The extent and curvature of the cornea and the size and curvature of the facets afford the most important indications as to the manner in which vision is accomplished. In the true compound eye, I think the structure indicates that J. Müller's theory of vision is the most probable; this is also Dr. Grenacher's view, and it is supported, as I shall now endeavour to show, by the curvature of the cornea and the size of the corneal facets in different insects, as well as in different parts of the same eye.

The semi-compound eye introduces no new difficulty in this theory, it is probable, I think, that more than a single luminous impression is received by the elements which are situated behind each facet, and that these correspond with portions of the field of vision which are remote from each other, the central rod cell of one facet corresponding to one of the peripheral rod cells of some other facet; the extreme complexity of the connexions between the cells of the ganglionic retina renders this view not improbable.

In order to determine the effect of the long fine highly refractive threads of the eyes of insects upon the light, I made some experiments on the transmission of light through fine threads of glass.

I took a capillary tube of glass $\frac{1}{500}$ of an inch in thickness, about $\frac{1}{100}$ of an inch in diameter, and an inch in length, placed it upright in a small trough of water under the microscope and examined it with an inch objective. I found that no light passed through the lumen of the tube, but that the section of the wall of the tube appeared brightly illuminated. I next placed a few fine glass threads, drawn from a glass rod, in the interior of the tube; these were as nearly as possible the same length as the tube and measured $\frac{1}{1000}$ of an inch in diameter. The upper end of each of these rods appeared as a brightly illuminated disk in the dark field; when the focus of the microscope was altered the disk enlarged, showing that the rays left the rod in a divergent direction; in some cases when the ends of the rods lay beyond the focus of the microscope, the disks of light exhibited grey rings, the result of interference.

When the lower ends of these rods were lenticular, or fused into a drop, or drawn into a cone, the phenomena were the same, and in all cases the action of an oblique pencil, even when the obliquity was very slight, was feeble as compared with that of a pencil having the direction of the axis of the rod.

These results are such as would be predicted on the undulatory theory; all the light passing into the rod, except very oblique rays, would be totally reflected, without any change of phase in the undulations, at the surface of the glass, whilst all except the axial rays would be very much enfeebled by numerous reflections and interference from the different lengths of the paths of the rays. I think threads of a highly refractive character immersed in a medium of a less refractive index, when less than $\frac{1}{5000}$ of an inch in diameter, would destroy the effect of rays of only very small obliquity by interference.

In order to determine the effect of the pigment, I covered the exterior of some glass rods of $\frac{1}{500}$ of an inch in diameter with black varnish, and I then found it impossible to transmit any rays of even the slightest obliquity through half an inch of such a rod.

From these facts I think it may be concluded that it is probable that the highly refractive structures may be regarded in the light of

luminous points, which serve as stimuli in exciting the recipient protoplasm in which their ends are imbedded.

The focus of the facet when this is lenticular, in all the insects which I have examined, is situated considerably deeper than the outer end of the rhabdion and below the surface of the rod cells in the microrhabdic eye, so that even for objects as close as $\frac{1}{10}$ of an inch to the cornea, we have to deal with convergent rays and not with a focal point. This indicates some mode of nerve stimulation other than the union of homocentric pencils, in a point beneath the compound cornea in relation with the recipient elements. Considering the small size of the parts, I think it quite possible that we must look to the phenomena of interference for the explanation; at least, they must play an important part in the phenomenon.

Whatever may be the manner in which vision is accomplished, the size of the corneal facets and the general curvature of the cornea renders the theory of J. Muller highly probable. It is true that Claperède has expressed the reverse opinion, but I shall endeavour to show that he has done so on insufficient data. According to his calculation, a bee should be unable to distinguish objects of less than eight inches in diameter at a distance of twenty feet from it. This calculation is based on the idea that the acuity of vision in this insect is the same in all parts of the field of vision, and that the general surface of the common cornea is approximately a segment of a sphere. This is not the case, for the angles subtended by the adjacent facets in the centre of the cornea, which is considerably flattened, is not more than half a degree at the most; so that on J. Muller's theory, supposing each facet to give rise to only a single luminous impression, the bee should be able to distinguish objects of about two inches in diameter at a distance of twenty feet, an acuity of vision quite equal to account for all the phenomena of vision in bees.

I have measured the curvature of the cornea of a number of insects, with a view to determining the angles made by the lines of vision drawn from the centre of adjacent facets. This is done in the following manner:—A magnified image of the cornea is thrown on a sheet of white paper, by means of a microscope and camera lucida, and the curve of its profile drawn; in this way I have found the principal meridians. These curves approach more or less closely to an epicycloid.

It is easy with such curves and the size of the corneal facets to determine the angles made by adjacent facets. The angles vary inversely as the radius of curvature, and, therefore, the acuity of vision varies directly as the radius of curvature when the diameter of the facets remains the same, and inversely as the diameter of the facets when these vary in size. In many insects, as *Tabanus*, the peripheral facets of the cornea are twice or three times the diameter

of those in the centre, and the radius of curvature is very short at the extreme periphery.

In most insects the acuity of vision determined in this manner diminishes very rapidly at the periphery of the field. In the centre of the field it enables them to perceive, as distinct, objects which subtend one degree. In *Æschna grandis* the sharpness of vision is much greater, as the adjacent facets make an angle of only eight minutes with each other. This is the least angle I have measured in any insect, but I have no doubt, from the nature of the curve forming the meridians of the eye in the great dragon flies, that a small part of the centre of the field has a much greater acuity of vision than this; in the wasp the angle subtended by the smallest visual perceptions is twice as great as in *Æschna;* and in the bee it is half a degree.

The direction of the visual line, or the line perpendicular to the compound cornea in the centre of the field of most acute vision, varies in different insects. In the predaceous kinds it is directed forwards in the plane of the body, or forwards and outwards, making an angle of 30° between the visual lines of the two eyes. In the pollen feeders it is directed downwards as well as forwards and outwards.

The size of the corneal facets varies in different insects from $\frac{1}{2000}$ to $\frac{1}{750}$ of an inch in diameter. Their size, except in a few insects, is dependent on the size of the insect, the largest insects having the largest and the smallest the smallest corneal facets. From this it follows that the vision of large insects is more perfect than that of small ones, except where the curvature of the cornea is very flat. This corresponds with the manner in which the insects fly. For instance, the small Diptera fly round in small circles, and seldom leave the place in which they first attain their adult condition, except when borne away by currents of air, whilst the larger species take long flights when disturbed or in search of food. The experiments of Muller and others have shown that the direction and length of the flight of insects depends largely on the visual powers of the insect. The forward flight of *Tabanus* and of many flies corresponds with the direction of their visual line, and the same may be said of the lateral movements of the large dragon flies.

The mimicry of insects, especially that between the Diptera and the Hymenoptera is sufficiently close to be a protection or advantage to the unarmed insect, and is such that it would render the one indistinguishable from the other, or the two insects would be scarcely to be distinguished under conditions of vision equal to those with which the insects appear to be endowed except at very close quarters.

In the extreme periphery of the cornea the adjacent facets make an angle of from 30′ in wasps and some other Hymenoptera, to 12° in many insects. In the microrhabdic eye of *Tipula* the curvature of the common cornea approaches the segment of a hemisphere.

In most insects the field of vision has a small region common to the two eyes in the vicinity of the mouth; it is chiefly developed in the predatory species, and probably serves in determining the distance of their prey from their mandibles.

III. "Measurements of Electrical Constants. No. II. On the Specific Inductive Capacities of Certain Dielectrics." By J. E. H. GORDON, B.A. Camb. First Series. Communicated by Professor J. CLERK MAXWELL, F.R.S. Received March 9, 1878.

(Abstract.)

The author has, under Professor Clerk Maxwell's directions, carried out some measurements of specific inductive capacities by a new method. The essential features of it are:—

(1.) It is a zero method.

(2.) The electrified metal plates never touch the dielectrics.

(3.) No permanent strain is produced or charge communicated, as the electrification is reversed some 12,000 times per second.

The potentials of the electrified plates were about equal to that of 2,000 cells.

The following are the results obtained:—The solid dielectrics were plates 7 inches square, and from $\frac{1}{4}$ inch to 1 inch thick.

Dielectric.		Specific Inductive Capacity.		
Ebonite, 4 slabs of thickness, $\frac{3}{4}$, $\frac{1}{2}$, $\frac{1}{2}$, $\frac{1}{4}$ inch, about.	(1.)	1·5593	Mean	1·56215
	(2.)	1·5553		
	(3.)	1·5671		
	(4.)	1·5669		
Best quality gutta percha				1·5939
Chatterton's compound				1·6080
India-rubber, black				1·5502
India-rubber, vulcanised				1·5988
Sulphur				1·6127
Shellac				1·6362
Solid paraffin, sp. gr. ·9109 at 11° C. Melting point 68° C. 6 slabs, each $\frac{3}{4}$-inch thick, about.	(1.)*	1·4986	Mean......	1·49753
	(2.)	1·4943		
	(3.)	1·4920		
	(4.)	1·5033		
	(5.)	1·4936		
	(6.)	1·5034		

* These results are corrected for cavities in the plates. The mean of the uncorrected determinations is 1·4864.